SRF QWR Gun at BNL CeC PoP

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Content

- Introduction
- Temptation and Questions need to answer
- Gun Design
- Performance
- Discussion
Introduction

- What is CeC PoP
  - SRF accelerator for proof-of-principle Coherent electron Cooling experiment
  - Goal of this experiment: provide high bunch charge electron (up to 5 nC) to cool a single bunch in RHIC

- The SRF portion

  704 MHz 5-cell elliptical cavity

  112 MHz Quarter Wave gun

From inside RHIC ring
Temptation and Questions need to answer

- Temptation of SRF gun:
  - CW beam
  - Relatively high E field at the cathode surface
  - Good vacuum due to cryo-pumping.

- Questions need to address:
  - Will K$_2$CsSb cathode survive the SRF cavity?
  - Will SRF cavity survive the K$_2$CsSb cathode?
Cavity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>112 MHz</td>
</tr>
<tr>
<td>R/Q (Acc. Def.)</td>
<td>126</td>
</tr>
<tr>
<td>Q₀</td>
<td>&gt;3.5 × 10⁹</td>
</tr>
<tr>
<td>Operation Temp.</td>
<td>4.5 K</td>
</tr>
<tr>
<td>Accelerating Voltage</td>
<td>1.5-2 MV</td>
</tr>
<tr>
<td>$E_{pk}/V_{acc}$</td>
<td>19.1 m⁻¹</td>
</tr>
<tr>
<td>$E_{pk}/E_{cath}$</td>
<td>2.63</td>
</tr>
<tr>
<td>$B_{pk}/V_{acc}$</td>
<td>36.4 mT/MV</td>
</tr>
<tr>
<td>Bunch Charge</td>
<td>1-5 nC</td>
</tr>
<tr>
<td>Bunch repetition Rate</td>
<td>78 kHz</td>
</tr>
</tbody>
</table>
- Made of Stainless steel, coated with 25 um copper and 1um gold;
- Qext adjustable from 5e6 to 8e7;
- Travel distance: 3 cm;
- Water cooled to room temperature.
Cathode Stalk

Varying diameter to form quarter-wave transformer to decrease RF loss.

- Stainless steel, 25 μm copper, 1 μm gold;
- Quarter-wave transformer, reduces the transverse field on cathode;
- Water cooled to room temperature;
- Rexolite® “spider” serve as support.

THP107  Mechanical Design of the 112 MHz SRF GUN and the 704 MHz 5-cell SRF Cavity for CeC PoP Experiment
Cathode Fabrication

- Heat the substrate at 350 C for 6 hours;
- hold it at 90 C;
- 10 nm Sb approximately 1 Å/s;
- raised the substrate’s temperature to 130 C;
- ~20 nm of potassium @ 0.6 Å/s;
- Then the heater was turned down in order for the substrate to be cooled at around 1 C/min;
- Evaporated Cs and watch QE increased steadily;
- When the photocurrent reached a plateau, turn off heater, turn on cold N₂, reduce Cs until 80 C;
- Cold down to room temperature quickly by cold N₂.

E. Wang, ERL2015

“Suite case”
The cathode is moved into transport cart which has low $10^{-10}$ torr scale vacuum.

Disconnecting the transport cart from the preparation system and connecting the cart to the SRF gun require a class 100 clean enclosure.

The loadlock section is baked about 2 days and reach $10^{-9}$ torr scale Vacuum.

We keep monitoring the QE evolution inside the transport cart.
Beam Performance

- World record bunch charge for an SRF Gun
  - 10.7 nC per bunch maximum achieved
- Record low normalized emittance: 0.32 mm mrad at 0.5 nC
- QE lifetime from one to two months
  - Room temperature water cooled cathode (i.e. not cold)
  - Requires automatic He blowout system in case of water flow failure

Measurements by Kentaro Mihara

Early results were presented by I. Pinayev in NAPAC2016

THP079 Performance of the Coherent Electron Cooling SRF Accelerator
Multipacting and Mitigation

- MPs? Plenty!
  - 2kV, 22 kV, 30 kV, and 40 kV …
  - Predicted by simulation and encountered in real.
- Will kill the cathode instantly if not dealt with care.
- Break through required strong coupling (for which we have the ability to adjust the FPC)
- LLRF implemented automated turning on script to prevent excessive trap time.
LLRF Script Solution for Gun Start Operation

- Lengthen period between attempts from \(~ 20\) min to \(~ 40\) min \(\Rightarrow 5^{th}\) attempt = successful turn on.
- Cathode QE not impacted by turn on attempts as MP related vacuum activity is kept minimal.

Failure to achieve voltage in \(20\) ms results in turn off of drive.

1 kV turn on (2.3 kV MP level just above) to allow PLL to lock on to cavity resonance.
Cavity Performance over years

Typical Gun voltage vs radiation

2016  4 cathodes  2017

1.1 MV  260 mrem

1.0 MV  250 mrem
Conclusion

- Our SRF gun generate electron bunches with
  - Very low normalized projected emittances (sub-μm at 1 nC).
  - Charge per bunch exceeding 10 nC.
  - Average current reached 150 uA.

- The high QE room temperature CsK$_2$Sb photocathodes operate for months in 1.23 MeV CW SRF gun without any significant degradation. We did not detect any degradation caused by generating CW electron beam.
Reference

- Kentaro Mihara, Vladimir N. Litvinenko, Irina Petrushina, et al., "Emittance Measurements and Simulations from SRF Gun in CeC Accelerator", FEL2017, Santa Fe, NM, USA
- J.C. Brutus, S. Belomestnykh, Y. Huang, V. Litvnenko, et al., “Mechanical Design of 112 Mhz SRF Gun FPC for CeC PoP Experiment”, PAC2013, Pasadena, CA, USA